AUTOMATED ANALYSIS OF INTERFACE TIMING MEASUREMENTS

by

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Related Applications

This application claims priority of United States provisional application Serial Number 60/282,236, filed April 6, 2001.

Field of the Invention

This application relates generally to an interface between devices of a computer system and more particularly to a tool for verification of interface timing measures against an industry standard.

Background of the Invention

Calculation, analysis and verification of interface timing measures of a disc drive-host computer interface against an industry standard may be used in both design and product assurance phases of disc drive qualification in order to guarantee that the disc drive operates as expected over a bus interface with the host computer. Furthermore, drive manufacturers perform such processes to ensure that no conditions exist that would be detrimental to operation of the host computer or other devices coupled to the bus. Currently, disc drive manufacturers utilize the following manual process to calculate, analyze and verify interface timing measures against industry standards, such as, without limitation, Serial Advanced Technology Attachment (SATA), Parallel ATA (PATA) and Small Computer System Interface (SCSI). First, a host controller card is used to exercise the disc drive under specific conditions while a bus analyzer is used to capture the entire test stream, also referred to as a bus trace, or more generally, a communication trace. A small sample of timing measurements, also referred to as timing measures, is then manually parsed on a bus analyzer and the individual timing measures are compared to the appropriate nominal and range times of protocol measures from the applied industry standard (i.e., Serial ATA, Parallel ATA, and SCSI).

Although current drive manufacturers may calculate, analyze and verify interface timing measures against industry standards at the disc drive design level, the aforementioned manual process is generally too tedious and time-consuming to administer at the disc drive development level. That is, current drive manufacturers typically only test for design flaws, thereby ignoring the possibility that specific hardware and/or firmware components of an assembled disc drive may actually contain a manufacturing flaw. Another problem associated with the earlier-described manual process for calculating, analyzing and verifying interface timing measures against industry standards for disc drive-host computer interfaces relates to the relatively small sample of timing measures taken from the bus trace. This extreme undersampling respective of the entire population of timing measures present in the bus trace may result in incorrect determinations of whether a disc drive-host computer interface meets or fails each protocol measure of the applied industry standard. However, due to the tedious nature of this process, it is not feasible to increase the sampling of timing measures used in evaluating whether the interface complies with the industry standard.

Summary of the Invention

Against this backdrop the present invention has been developed. An embodiment of the present invention is a system for evaluating whether an interface between a host device and a target device complies with specifications of an industry standard, such as, without limitation, SCSI, Serial ATA and Parallel ATA. More specifically, the system of this embodiment utilizes a bus analyzer to scan a communication trace transmitted between the host device and the target device. The communication trace may be defined as various communications between the host device and the target device transmitted as signal lines over a bus. As such, the communication trace may include both data and control communications between the devices. The bus analyzer generates a log file from the communication trace that records logic transitions of the data and control communications in the communication trace.

This embodiment of the system of the present invention includes a timing event analysis module for detecting one or more timing measures in the communication trace and a timing measure analysis module for analyzing the detected timing measure(s) to determine whether the

interface complies with the applied industry standard. More specifically, the timing event analysis module analyzes the logic transitions recorded in the log file to identify the timing measure(s) present in the communication trace. After the timing measure(s) are identified, the timing measure analysis module evaluates each timing measure against a timing measure protocol specified by the industry standard. For example, the timing measure analysis module may compare the length of each timing measure to an exemplary length specified by the timing measure protocol to determine whether the timing measure complies with a specification of the industry standard.

Embodiments of the invention may be implemented, for example, as a computer-readable program storage device which tangibly embodies a program of instructions executable by a computer system to evaluate timing measures of an interface between devices connected over a bus against an industry standard for the interface to determine whether the interface complies with the industry standard.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. **1** is a plan view of a disc drive incorporating a preferred embodiment of the present invention showing the primary internal components.

FIG. **2** is a functional block diagram generally showing the main functional components used to control the disc drive of FIG. **1**.

FIG. **3** is a functional diagram of a trace evaluation system for evaluating a bus trace between devices communicating over a bus in accordance with an embodiment of the present invention.

FIG. **4** is a timing diagram illustrating logic transitions of signal lines of the bus trace of FIG. **3** in accordance with an exemplary embodiment of the present invention.

FIG. **5** is a flow diagram that illustrates operational processes for evaluating timing measures of a bus trace between devices communicating over a bus in accordance with an embodiment of the present invention.

FIG. **6** is a flow diagram that illustrates operational processes shown in FIG. **5** in more detail.

Detailed Description

The present invention and its various embodiments are described in detail below with reference to the figures. When referring to the figures, like structures and elements shown throughout are indicated with like reference numerals.

A disc drive **100** constructed in accordance with a preferred embodiment of the present invention is shown in FIG. **1**. The disc drive **100** includes a base **102** to which various components of the disc drive **100** are mounted. A top cover **104**, shown partially cut away, cooperates with the base **102** to form an internal, sealed environment for the disc drive **100** in a conventional manner. The components include a spindle motor **106** which rotates one or more discs **108** at a constant high speed. Information is written to and read from tracks on the discs **108** through the use of an actuator assembly **110**, which rotates about a bearing shaft assembly **112** positioned adjacent to the discs **108**. The actuator assembly **110** includes a plurality of actuator arms **114** which extend towards the discs **108**, with one or more flexures **116** extending from each of the actuator arms **114**. Mounted at the distal end of each of the flexures **116** is a read/write head **118** which includes an air bearing slider enabling the read/write head **118** to fly in close proximity above the corresponding surface of the associated disc **108**.

The spindle motor **106** is typically de-energized when the disc drive **100** is not in use for extended periods of time. In accordance with one embodiment of the present invention, the read/write heads **118** are moved over park, or landing, zones **120** near the inner diameter **136** of the discs **108** when the drive motor is de-energized. The read/write heads **118** may be secured over the landing zones **120** through the use of an actuator latch arrangement, which prevents inadvertent rotation of the actuator assembly **110** when the heads **118** are parked. Although the landing zone **120** is shown in FIG. **1** as located in close proximity to the inner diameter **136** of

the discs **108**, a landing zone **120** may also be located in close proximity to an outer diameter **138** of the discs **108**. Furthermore, a landing zone **120** may be located on any portion of the discs **108** between the outer diameter **138** and the inner diameter **136** of the discs **108**. Alternatively, the read/write heads **118** may be removed from the surface of the discs **108** by load/unload ramps positioned in close proximity to the outer diameter **138** when the drive motor is de-energized. As such, the read/write heads **118** may be secured by the ramps to prevent inadvertent rotation of the actuator assembly **110** when the discs **108** are spinning at a velocity insufficient to maintain an air bearing between the sliders and the discs **108**. The heads **118** are maintained on the ramps in the park position through the use of an actuator latch arrangement, which prevents inadvertent rotation of the actuator arms **114** when the heads are parked. This latch arrangement is typically a magnetic latch which magnetically holds the actuator against a stop.

The radial position of the heads **118** is controlled through the use of a voice coil motor (VCM) **124**, which typically includes a coil **126** attached to the actuator assembly **110**, as well as one or more permanent magnets **128** which establish a magnetic field in which the coil **126** is immersed. The controlled application of current to the coil **126** causes magnetic interaction between the permanent magnets **128** and the coil **126** so that the coil **126** moves in accordance with the well-known Lorentz relationship. As the coil **126** moves, the actuator assembly **110** pivots about the bearing shaft assembly **112** and the heads **118** are caused to move across the surfaces of the discs **108**.

A flex assembly **130** provides the requisite electrical connection paths for the actuator assembly **110** while allowing pivotal movement of the actuator assembly **110** during operation. The flex assembly includes a printed circuit board **132** to which head wires (not shown) are connected; the head wires being routed along the actuator arms **114** and the flexures **116** to the heads **118**. The printed circuit board **132** typically includes circuitry for controlling the write currents applied to the heads **118** during a write operation and for amplifying read signals generated by the heads **118** during a read operation. The flex assembly terminates at a flex bracket **134** for communication through the base **102** to a disc drive printed circuit board (not shown) mounted to the bottom side of the disc drive **100**.

Referring now to FIG. **2**, shown therein is a functional block diagram of the disc drive **100** of FIG. **1** generally showing the main functional circuits which are resident on the disc drive printed circuit board and used to control the operation of the disc drive **100**. The disc drive **100** is shown in FIG. **2** to be operably connected to a host computer **140** in which the disc drive **100** is mounted in a conventional manner. Control communication paths are provided between the host computer **140** and a disc drive microprocessor **142**, the microprocessor **142** generally providing top level communication and control for the disc drive **100** in conjunction with programming for the microprocessor **142** stored in microprocessor memory (MEM) **143**. Specifically, the disc drive **100** communicates with the host computer **140** using a bus **160**. A bus is generally defined as a path carrying data between two or more devices. The bus **160** used to communicate data and control lines between the host computer **140** and the disc drive **100** is shown in dashed arrows because the bus **160** is not in and of itself a single physical object, but rather a collection of cabling/wiring that, taken together, makes up a communication channel between the host computer **140** and the disc drive **100**. As such, the bus **160** carries the cables/wires used to transfer data between a disc drive interface **144** and the host computer **140** as well as the cables/wires used to transfer data between the microprocessor **142** and the host computer **140**.

The MEM **143** can include random access memory (RAM), read only memory (ROM), and other sources of resident memory for the microprocessor **142**. The discs **108** are rotated at a constant high speed by a spindle control circuit **148**. The radial position of the heads **118** is controlled through the application of current to a coil in the actuator assembly **110**. A servo control system **150** provides such control.

Data is transferred between the host computer **140** and the disc drive **100** by way of the disc drive interface **144**, which includes a buffer **145** to facilitate high speed data transfer between the host computer **140** and the disc drive **100**. Data to be written to the disc drive **100** are thus passed from the host computer **140** to the buffer **145** and then to a read/write channel **146**, which encodes and serializes the data and provides the requisite write current signals to the heads **118**. To retrieve data that has been previously stored by the disc drive **100**, read signals are generated by the heads **118** and provided to the read/write channel **146**. The interface **144** performs read

signal decoding, error detection, and error correction operations. The interface **144** then outputs the retrieved data to the buffer **145** for subsequent transfer to the host computer **140**.

FIG. **3** shows a functional block diagram of a trace evaluation system **300** in accordance with an embodiment of the present invention. The trace evaluation system **300** monitors and analyzes communications between two devices associated with a computer system. More specifically, the trace evaluation system **300** analyzes data and control signals transmitted in a communication trace over the bus **160** to detect timing measures occurring on the trace and thereafter evaluate the timing measures against threshold parameters, or protocols, specified by an industry standard.

Communication traces between various kinds of devices may be evaluated by the trace evaluation system **300**. Each device may generally be referred to as either an initiator device or a target device. The initiator device, which may also be referred to as a host, initiates communication with another device. The target device receives the initial communication from the initiator and responds. The communication trace, which includes all communications between the devices over a predefined period of time beginning with the initial communication from the initiator, may also be referred to as a bus trace due to the fact that the communications are transmitted between devices using the bus **160**. In the exemplary embodiment of the present invention shown in FIG. **3**, the initiator is a host computer **140** and the target is a disc drive **100**. The disc drive **100** and the host computer **140** are operably connected, and thus control and data signal lines are transferred between the drive **100** and the host computer **140**, using the bus **160**.

Various industry standards provide specifications governing the transfer of data over a bus **160**, including, without limitation, Serial Advanced Technology Attachment (SATA), Parallel ATA (PATA), Fibre Channel Arbitrated Loop (FC-AL) and Small Computer System Interface (SCSI). The aforementioned industry standards generally provide protocols specifying the occurrence and length of timing measures occurring on communications transmitted over a bus **160**. In accordance with one embodiment, and not by means of limitation, the industry standard described herein comprises a SCSI specification, and therefore, the timing measure protocols used by the trace evaluation system **300** are SCSI protocols. The SCSI standard, as

well as the other industry standards noted above, is widely known and therefore not described in detail herein.

The host computer **140** is shown communicating with the disc drive **100** using the bus **160**. As such, the trace evaluation system **300** monitors and analyzes various communications between the host computer **140** and the disc drive **100** on the bus **160**. As noted above, the communications are preferably contained in a selected communication trace bounded by an initial communication and an ending, or final, communication. Because the communications are described below as being transmitted over the bus **160**, as noted above, the communication trace is hereinafter referred to as a bus trace. In accordance with an embodiment, the bus trace may comprise test communications transmitted between the host computer **140** and the disc drive **100** during disc drive design and development. As such, the trace evaluation system **300** may be used in this situation to detect design flaws in the disc drive model being tested. In accordance with another embodiment, the bus trace may comprise test communications transmitted between the host computer **140** and the disc drive **100** following disc drive assembly, possibly while the drive **100** is currently on the manufacturing line. As such, the trace evaluation system **300** may be used in this situation to detect manufacturing flaws in the specific disc drive **100** being tested. In accordance with yet another embodiment, the bus trace may comprise communications transmitted between a host computer **140** and a disc drive **100** during operation of the disc drive **100** following delivery of the drive **100** to a customer. As such, the trace evaluation system **300** may be used in this situation to detect run-time or operational errors in the disc drive **100** outside of the design, development or manufacturing environment.

The trace evaluation system **300** preferably includes a bus analyzer **304**, a timing event analysis module **312** utilizing a bus analyzer library **314**, and a timing measure analysis tool **310**. The bus analyzer **304** monitors the communications between the host computer **140** and the disc drive **100** to output a binary log file **306** indicative of logic transitions in communications being transmitted over the bus **160**. The communications are preferably transmitted over the bus **160** in the form of signal lines, such as data lines and control lines, contained within each communication trace. FIG. **4**, described below, illustrates in more detail exemplary signal lines that may be included in such communications between the drive **100** and the host computer **140**.

The binary log file **306** is input to the timing event analysis module **312**. The timing event analysis module is preferably a software module, i.e., a dynamic link library (DLL) or a stand-alone executable program (EXE), that reads the binary log file **306** to identify predefined timing events **316** in the bus trace. A timing event is preferably defined as a transition in logic state, e.g., low to high or high to low, of any single signal line of the bus trace. Thus, the term "timing event" is used herein to define a single logic transition occurring in the bus trace between two devices. Specifically, the timing event analysis module **312** scans each signal line in the bus trace, and more specifically, each timing event, to identify timing measure conditions specified by the applied industry standard. The timing measure conditions correspond to appropriate start and ending conditions for timing measures in the bus trace. A timing measure is preferably defined as the amount of time between one defined state occurring on a communication trace, i.e., the bus trace in accordance with this embodiment, to another defined state. As such, each timing measure has an associated type, regardless of the industry standard applied to the measure. Any number of timing measures of a particular type may exist in a bus trace. Indeed, a bus trace may include only one timing measure of a particular type.

The timing measure conditions direct the timing event analysis module **312** to identify specific timing events in the bus trace that either singly or in combination with other timing events represent either a beginning or an ending boundary for the timing measure. A timing measure condition may be a function of either multiple timing events or a single timing event. For example, one timing measure condition associated with a specific timing measure type for the host-drive interface may be defined as a change in transition state of multiple signal lines, whereas another timing measure condition associated with a separate timing measure type for the host-drive interface may be defined by a change in transition of a single signal line. Based on the type of bus analyzer **304** utilized, a bus analyzer library **314** may be used to enable scanning of the binary log file **306** by the timing event analysis module **312**. The bus analyzer library **314** is a set of functions compiled into the timing event analysis module **312** that allows the module **312** to access the data contained in the binary log file **306**. As such, the binary log file **306** is shown in FIG. **3** being input to the timing event analysis module **312** via the bus analyzer library **314**.

The timing event analysis module **312** reads the time stamp for each identified start and ending condition and thereafter outputs this information to the timing measure analysis tool **310** in a format such that the timing measure analysis tool **310** may evaluate occurrence of the timing measure condition **316** and length, in time, of the timing measure to which the timing event **316** is associated. The timing measure analysis tool **310** then matches each start condition with an associated ending condition based on the type associated with each timing measure. That is, the timing measure analysis tool **310** identifies the timing measures on the bus trace by matching each start condition with a corresponding ending condition. The timing measure analysis tool **310** then calculates the time differences between corresponding starting and ending conditions associated with each timing measure to determine the length, in time, of each timing measure. The timing measure analysis tool **310** also performs various statistical analyses on the calculated timing measures, including, without limitation, determining an average length, in time, of all timing measures of a particular type. The timing measure analysis tool **310** compares the average length, in time, associated with each particular timing measure type to timing measure protocols **308** specified by the applied industry standard. Based on these comparisons, the timing measure analysis tool **310** generates a report **320** illustrating whether and to what degree the host-drive interface conforms, or follows, the applied specification.

Referring now to FIG. **4**, shown therein is a timing diagram illustrating an exemplary representation of signal lines (**402, 404, 406, 408, 410**) contained in a bus trace **400** of communications being transmitted between devices over a bus **160** in accordance with an embodiment of the present invention. The timing diagram is shown in FIG. **4** and described below to briefly illustrate the concept of timing measures, timing events, and timing measure conditions occurring on signal lines (**402, 404, 406, 408, 410**) in the bus trace **400**. As such, it should be appreciated that the timing diagram is but one representation of specific timing measures, timing events, and timing measure conditions occurring on a bus trace **400** between devices. Indeed, depending on the communications being exchanged between devices, a bus trace **400** may comprise any number of signal lines, and thus, construction of the terms "timing measures," "timing events," and "timing measure conditions" should not be limited to encompass only the exemplary signal lines (**402, 404, 406, 408, 410**) included in the bus trace **400**.

Likewise, signal lines may carry information associated with any form of content transmitted between devices. As noted above, although the devices are described below as a host computer **140** and a disc drive **100**, it should be appreciated that the devices may be any type of device communicating over a bus **160**.

The timing diagram **400** includes a first signal line **402**, a second signal line **404**, a third signal line **406**, a fourth signal line **408** and a fifth signal line **410**. Each signal line **402, 404, 406, 408** and **410** reveals various timing events defined as transition points in time wherein the logic states of the signal lines **402, 404, 406, 408** and **410** toggle from logic high to logic low, or vice-versa. That is, the timing events are shown in FIG. **4** as changes in logic, either from high to low or from low to high, occurring on each of the exemplary signal lines **402, 404, 406, 408** and **410**. A timing measure is preferably defined by starting and ending timing measure conditions, which, as noted above and described below, may be a function of timing events on either multiple signal lines **402, 404, 406, 408** and **410** or a single signal line, i.e., **402, 404, 406, 408** and **410**. As an example of a timing measure having conditions that are functions of timing events on multiple signal lines, a start condition may be specifically defined to occur following occurrence of a timing event on both the second **(404)** and the first **(402)** signal lines. That is, the start condition occurs at the first-occurring timing event **412** on the second signal line **404** because a timing event **411** has already occurred on the first signal line **402**. As described with the start condition, the ending condition for this exemplary timing measure may also be defined as a function of timing events occurring on multiple signal lines **402, 404, 406, 408** and **410**. For example, the ending condition may be specifically defined to occur following occurrence of subsequent timing events on both the second **(404)** and the first **(402)** signal lines. That is, the ending condition occurs at the second timing event **414** on the second signal line **404** because at least one timing event **413** has already occurred on the first signal line **402**. As such, the timing measure for this set of start and ending conditions begins at the first timing event **412**, in time, occurring on the second signal line **404** and terminates at the second timing event **414**, in time, occurring on the second signal line **404**.

To illustrate a timing measure having conditions that are functions of timing events on a single signal lines, a start condition may be specifically defined at the first timing event **416** on

the fourth signal line **408** and every other timing event thereafter, wherein each start condition is succeeded by an ending condition. As such, the first-occurring timing measure on the fourth signal line **408** begins at the first timing event **416**, in time, and concludes at the next timing event **418**, in time, occurring on the fourth signal line **408**.

Embodiments of the present invention may also be implemented as a computer-readable program storage device which tangibly embodies a program of instructions executable by a computer system for evaluating timing measures of an interface between devices against an industry standard for the interface. As such, the logical operations of the various embodiments of the present invention may be implemented (1) as a sequence of computer implemented acts or program modules running on a computing system and/or (2) as interconnected machine logic circuits or circuit modules within the computing system. The implementation is a matter of choice dependent on the performance requirements of the computing system implementing the invention. Accordingly, the logical operations making up the embodiments of the present invention described herein are referred to variously as operations, structural devices, acts or modules. It will be recognized by one skilled in the art that these operations, structural devices, acts and modules may be implemented in software, in firmware, in special purpose digital logic, and any combination thereof without deviating from the spirit and scope of the present invention as recited within the claims attached hereto.

Referring now to FIG. **5**, a flow diagram illustrating operations of an evaluation process **500** for evaluating timing measures of an interface between devices against an industry standard for the interface is shown in accordance with an embodiment of the present invention. Specifically, the evaluation process **500** monitors a communication trace between a host device, such as the host computer **140**, and a target device, such as the disc drive **100**, to detect and thereafter analyze timing measures occurring on the trace. Because the communications are described below as being transmitted over the bus **160**, as noted above, the communication trace is hereinafter referred to as a bus trace, such as the bus trace **400** shown in FIG. **4**. The evaluation process **500** may be utilized to evaluate multiple timing measure types occurring on the bus trace between the devices. However, for illustrative and claritive purposes, the evaluation process **500** is described below as evaluating a single timing measure type against a timing

measure protocol specified by the industry standard. It should be appreciated that the evaluation process **500** may be implemented or performed multiple times, sequentially or simultaneously, to evaluate multiple timing measure types against multiple timing measure protocols specified by an industry standard.

Although the evaluation process **500** is described below as evaluating timing measures on a bus trace between a host computer **140** and a disc drive **100**, the evaluation process may be used to evaluate timing measures on a trace between any two devices that communicate using a bus **160**. The evaluation process **500** comprises an operation flow beginning with a start operation **502** and concluding with a terminate operation **518**. From the start operation **502**, the operation flow passes to a read operation **504**. The read operation **504** reads the bus trace between the host computer **140** and the disc drive **100** to identify timing measures of a particular type. In accordance with a preferred embodiment, the read operation **504** scans a binary log file, such as the binary log file **306** shown in FIG. **3**, generated by a bus analyzer **304** and representing the logic state transitions of signal lines in the bus trace. The read operation **504** continues reading the bus trace until a timing measure is detected in the trace by the detect operation **506**.

The detect operation **506** identifies the timing measure in the bus trace based on timing measure conditions associated with a timing measure protocol specified by the applied industry standard, i.e., Serial ATA, Parallel ATA or SCSI. More specifically, the detect operation **506** first detects a start condition identifying the beginning of the timing measure. After the detect operation **506** detects the start condition, the detect operation **506** searches for and thereafter detects an ending condition for the timing measure. That is, by locating the ending condition, the detect operation **506** identifies the timing measure, which, as described above, begins at the start condition and terminates at the ending condition. As noted above, start and ending conditions may be a function of one or more timing events on either multiple signal lines or a single signal line. Once the timing measure is detected, the operation flow passes to a log operation **508**.

The log operation **508** stores information associated with the timing measure in memory. In accordance with an exemplary embodiment, the log operation **508** may store information identifying the length, in time, from the start condition to the ending condition, thereby storing the magnitude, in length, of the timing measure identified by the detect operation **506**. The log

operation **508** may also time-stamp the start and ending conditions of the timing measure and thereafter store the time stamp with the information identifying the magnitude of the timing measure. The memory to which the aforementioned information is stored may be volatile (such as RAM), non-volatile (such as ROM, flash memory, etc.) or some combination of the two. From the log operation **508**, the operation flow passes to a second read operation **510**.

The second read operation **510** continues reading the bus trace between the host computer **140** and the disc drive **100** to identify subsequent timing measures of the type being detected by the evaluation process **500**. The second read operation **510** reads the bus trace until a query operation **512** detects either a subsequent timing measure or the end of the bus trace being evaluated. If the query operation **512** detects a subsequent timing measure, the operation flow returns to the log operation **508**. The log operation **508** logs each subsequently-occurring timing measure to memory and operation flow continues as previously described. If, however, no subsequent timing measures are detected, the end of the bus trace is assumed by the query operation **512** and operation flow passes to a calculate operation **514**.

The calculate operation **514** statistically analyzes each timing measure detected on the bus trace by the detect operation **506** and logged to the memory by the log operation **508** to render a representative timing measure for the timing measure type being evaluated by the trace evaluation process **500**. From the calculate operation **514**, the operation flow passes to an analysis operation **516**. The analysis operation **516** evaluates the representative timing measure against an industry standard specification for the host-drive interface. That is, the analysis operation **516** preferably compares the representative timing measure to a timing measure protocol specified by the industry standard to determine whether the host-drive interface conforms to the applied industry standard. From the analysis operation **516**, the operation flow concludes with the termination operation **518**.

FIG. **6** is an evaluation process **600** more particularly illustrating operations shown in the evaluation process **500** in accordance with an embodiment of the present invention. Specifically, the evaluation process **600** preferably detects, records and thereafter evaluates timing measures of multiple types during a single pass, or scan, of a bus trace occurring over a bus **160** providing communication paths between at least two devices associated with a computer system. In

accordance with an exemplary embodiment, the devices are hereinafter described as a host computer **140** and a disc drive **100**. It should be appreciated that the evaluation process **600** may be used in conjunction with any type of bus **160** connecting any two devices, and therefore the present invention should not be construed as limited to evaluation of a bus trace between a host computer **140** and a disc drive **100**. The evaluation process **600** shown in FIG. **6** comprises an operation flow beginning with a start operation **602** and concluding with a terminate operation **624**. From the start operation **602**, the operation flow passes to a define operation **604**.

The define operation **604** defines which timing measure types are to be evaluated against an industry standard. For example, if the two devices are connected using a SCSI bus, several exemplary signal lines may be "Busy," "Select," and "Acknowledge." As such, a timing measure type may be defined as a time in which all three exemplary lines have a logic state reading of high. Thus, the timing measure type in this example has a start condition occurring at a time when all three signal lines go high and an ending condition occurring at a time when only one of the signal lines goes low. Typically, a bus trace comprises multiple timing measures of each timing measure type. However, it is possible for a bus trace to include only a single timing measure of a particular type. In accordance with an embodiment, the define operation **604** includes receiving instructions from a user identifying which types of timing measures are to be detected, recorded and evaluated using the evaluation method **600**. Following the define operation **604**, the operation flow passes to a read operation **606**.

The read operation **606** reads the bus trace transmitted between the host computer **140** and the disc drive **100** to identify timing measures of the types defined by the define operation **604**. In accordance with a preferred embodiment, the read operation **606** scans a binary log file generated by a bus analyzer **304** and representing the logic state transitions of signal lines in the bus trace. The read operation **606** continues reading the bus trace until a timing measure condition is detected by the detect operation **608**. As shown using a double arrow, the operation flow repeatedly passes between the read operation **606** and the detect operation **608** until a timing measure condition is detected.

The detect operation **608** detects each timing measure condition, whether start condition or ending condition, by comparing timing measure conditions of protocol timing measures

specified by the industry standard against timing events on the signal lines of the bus trace being scanned. As noted above, a timing measure condition may be a function of one or more timing events occurring either on multiple signal lines or on a single signal line. For illustrative purposes, and not by means of limitation, timing measure conditions are described below as being functions of timing events occurring on multiple signal lines. As such, using the example illustrated above, a start condition may be defined as the logic state of the "Busy," "Select," and "Acknowledge" signal lines all read high. After the detect operation **608** detects a timing measure condition, the operation flow passes to a first query operation **610**.

The first query operation **610** determines whether the detected timing measure condition is a start condition or an ending condition. If the timing measure condition is a start condition, the operation flow passes to a first compile operation **611**. The first compile operation **611** first time stamps the start condition, as referenced from the beginning of the bus trace, and thereafter adds the time stamp, along with information identifying the timing measure type associated with the start condition, to a start condition stack in memory. The start condition stack contains a record of all start conditions occurring on the bus trace which have not been matched to an ending condition and thereafter logged into memory. Following the first compile operation **611**, the operation flow returns to the read operation **606** and thereafter continues as previously described.

If, however, the first query operation **610** determines that the timing measure condition is an ending condition, the operation flow passes to a match operation **613**. The match operation **613** first time stamps the time at which the ending condition occurs, as referenced from the beginning of the bus trace, and thereafter matches the detected ending condition to an associated start condition recorded in the start condition stack. Because a timing measure of a particular type may only occur once at a time, the match operation **613** matches each detected ending condition to a start condition based on the timing measure type of the ending condition. That is, in order for an ending condition of a particular type to occur, there must presently exist a single start condition in the start condition stack that is associated with the same timing measure type. After the ending condition is matched to an associated start condition by the match operation **613**, the operation flow passes to a second compile operation **614**.

The second compile operation **614** retrieves the matched pair of timing measure conditions and adds the matched pair to a log file of matched pairs for all timing measure types. The second compile operation **614** records the time stamp for each timing measure condition such that each matched pair is represented with a time stamp identifying the time of the start condition and a time stamp identifying the time of the ending condition. The absolute difference in the time stamps for the timing measure conditions of each matched pair is equal to the length, or magnitude in time, of the timing measure starting at the start condition and terminating at the ending condition. As such, the absolute difference between the magnitudes, or values, of the time stamps of each matched pair is recorded in the log file and categorized as a timing measure for a particular type. From the second compile operation **614**, the operation flow passes to a second query operation **616**.

The second query operation **616** determines whether all timing events of the signal lines in the bus trace have been scanned by the read operation **606** and therefore analyzed by the detect operation **608** to determine whether any more timing measure conditions exist in the bus trace. If the second query operation **616** determines that more timing events exist in the bus trace, the operation flow returns to the read operation **606** and continues as previously described. If, however, all timing events present in the bus trace have been scanned, the operation flow passes to a calculate operation **618**.

The calculate operation **618** utilizes the log file to calculate statistics associated with each timing measure detected in the bus trace as well as statistics for each timing measure type defined by the define operation **602**. As such, the calculate operation **618** preferably calculates the length, in time, of each timing measure and a representative timing measure for each type. The representative timing measure is preferably defined as the average length, in time, of all timing measures in a bus trace of a particular timing measure type. The calculate operation **618** may also calculate various other statistics associated with timing measures that are not discussed in detail herein, such as, without limitation, distributions of timing measures and other more advanced statistical measures. Following the calculate operation **618**, the operation flow passes to an analysis operation **620**.

The analysis operation **620** evaluates the representative timing measures of the timing measure types against an industry standard specification for the host-drive interface. That is, the analysis operation **620** preferably compares each representative timing measure to a timing measure protocol specified by the industry standard to determine whether the host-drive interface conforms to the industry standard. The timing measure protocol thus defines a minimum or maximum absolute value for the length, in time, of a particular timing measure. As such, a timing measure protocol may exist for each timing measure type defined by the define operation **602**. Furthermore, the analysis operation **620** may individually compare each timing measure of a particular type to the timing measure protocol specified by the applied industry standard for that particular timing measure type. As such, if a single timing measure does not meet the specifications required by the industry standard, the analysis operation **620** will identify that individual timing measure as not complying with the industry standard, regardless of whether an average of all timing measures of that particular type complies with the specification. Following the analysis operation **620**, the operation flow passes to a display operation **622**.

The display operation **622** outputs the results of the analysis operation **620** in the form of a report, such as the report **320**, detailing whether and to what extent any of the representative timing measures, or in accordance with an alternative embodiment, any of the timing measures detected in the bus trace, fail to comply with the applied industry standard. As such, the report **320** preferably includes a comparison of each timing measure statistic to an associated protocol specified by the industry standard. The report **320** may also include the time stamps of the timing measure conditions, both start and ending, as well as the length, in time, associated with each timing measure detected in the bus trace. Following the display operation **622**, the operation flow concludes with the termination operation **624**.

In summary, the present invention may be viewed as a system (such as **300**) for evaluating whether an interface between a host device (such as **140**) and a target device (such as **100**) complies with specifications of an industry standard. In accordance with a preferred embodiment, the system includes a bus analyzer (such as **304**) operable to scan a communication trace (such as **400**) transmitted over a bus (such as **160**) operably connected between the host device and the target device and record logic transitions (such as such as **411, 412, 413, 414, 416**

and **418**) of signal lines (such as **402, 404, 406, 408** and **410**) contained in the communication trace. A timing event analysis module (such as **312**) is preferably connected to the bus analyzer to analyze the logic transitions to identify a timing measure present in the communication trace. A timing measure analysis module (such as **310**) is connected to the timing event analysis module to evaluate the timing measure against a timing measure protocol (such as **308**) specified by the industry standard. The timing event analysis module may identify the timing measure by detecting a predetermined timing measure condition (such as **316**) in the communication trace, the timing measure condition being predefined by the timing measure protocol. As such, the timing measure condition may be detected in the communication trace following occurrence of a plurality of logic transitions (such as **411** and **412**), wherein each logic transition occurs on a separate signal line (such as **402** and **404**). Alternatively, the timing measure condition may be detected in the communication trace following occurrence of a logic transition (such as **416**) on a single signal line (such as **408**).

In accordance with a more specific embodiment, the timing measure analysis module may calculate a length, in time, from a start condition (such as timing event **412**) to an ending condition (such as timing event **414**) and thereafter compares the length to an exemplary length specified by the timing measure protocol to determine whether the timing measure complies with a specification of the industry standard. The timing measure analysis module may also create a report (such as **320**) detailing whether the timing measure complies with the protocol specified by the industry standard. The industry standard providing specifications for the interface between the devices may be Small Computer System Interface (SCSI) or Fibre Channel Arbitrated Loop. If the host device is a host computer and the target device is a disc drive, the industry standard may be Serial Advanced Technology Attachment (SATA).

In accordance with another embodiment, the present invention may be viewed as a computer-readable program storage device which tangibly embodies a program of instructions executable by a computer system to perform a method (such as in operation **500**) for evaluating whether an interface between a host device (such as **140**) and a target device (such as **100**) complies with an industry standard. The method of this embodiment preferably includes a step of scanning (such as in operation **502**) a communication trace (such as **400**) transmitted between the

host device and the target device, a step of identifying (such as in operation **506**) a timing measure present in the communication trace and step of evaluating (such as in operation **516**) the timing measure against a timing measure protocol (such as **308**) specified by the industry standard. The identifying step (such as in operation **506**) may include steps of detecting (such as in operation **616**) logic transitions (such as **411, 412, 413, 414, 416** and **418**) of signals lines (such as **402, 404, 406, 408** and **410**) contained in the communication trace and analyzing (such as in operation **608**) the logic transitions to identify the timing measure. More specifically, the analyzing step (such as in operation **608**) may include a step of detecting (such as in operation **610**) a timing measure condition (such as **316**) in the communication trace, wherein the timing measure condition is predefined by the timing measure protocol. The timing measure condition may be identified by the detecting step following occurrence of a plurality of logic transitions, wherein each logic transition occurs on a separate signal line. Alternatively, the timing measure condition may be identified by the detecting step following occurrence of a logic transition on a single signal line.

In accordance with an embodiment, the evaluating step (such as in operation **516**) may calculate (such as in operation **618**) a length, in time, from a start condition (such as timing event **412**) to an ending condition (such as timing event **414**) and thereafter compare (such as in operation **620**) the length to an exemplary length specified by the timing measure protocol to determine whether the timing measure complies with the a specification of the industry standard. The method may include a step of creating (such as in operation **622**) a report (such as **320**) detailing whether the timing measure complies with a specification of the industry standard based on evaluation of the timing measure against the timing measure protocol.

The method may further include a step of defining (such as in operation **604**) a specific timing measure type having a plurality of timing measures present in the communication trace. As such, the identifying step (such as in operation **506**) may detect each of the plurality of timing measures in the communication trace and the evaluating step (such as in operation **516**) may calculate (such as in operation **618**) a length, in time, of each of the plurality of timing measures and thereafter average the length of the plurality of timing measures to render a representative timing measure length. Finally, the evaluating step (such as in operation **516**) may compare

(such as in operation **620**) the representative timing measure length to an exemplary length specified by the timing measure protocol. Alternatively, the method may further include a step of defining (such as in operation **604**) a plurality of timing measure types, rather than a single timing measure type. As such, the evaluating step (such as in operation **516**) may evaluate (such as in operation **620**) the one or more timing measures associated with each timing measure type against a timing measure protocol specified by the industry standard as specific to each timing measure type. More specifically, the evaluating step (such as in operation **516**) may calculate (such as in operation **618**) a length, in time, of the one or more timing measures associated with each timing measure type, average (such as in operation **618**) the length of the one or more timing measures associated with each timing measure type to render a representative timing measure length for each timing measure type and compare (such as in operation **620**) the representative timing measure length for each timing measure type to an exemplary length specified by a timing measure protocol defined by the industry standard as specific to each timing measure type.

In accordance with yet another embodiment, the present invention may be viewed as a system (such as **300**) for evaluating whether an interface between a host device (such as **140**) and a target device (such as **100**) complies with an industry standard, wherein a bus analyzer (such as **304**) scans a communication trace (such as **400**) transmitted between the host device and the target device and creates a log file (such as **306**) recording logic transitions (such as **411**, **412**, **413**, **414**, **416** and **418**) of signals lines (such as **402**, **404**, **406**, **408** and **410**) contained in the communication trace. The system may include a timing event analysis module (such as **312**) analyzing the logic transitions to identify a timing measure present in the communication trace and a means for evaluating (such as **310**; such as in operation **516**) the timing measure against a timing measure protocol (such as **320**) specified by the industry standard.

It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present invention. For example, the device connected to and communicating with the host computer **140** via the bus **160** may be any type of device utilized by

a computing environment, and not just a disc drive **100**, as described in detail herein. As such, the host computer **140** may be connected via the bus **160** to any of the following devices, and thus, the trace evaluation system **300** and the trace evaluation process **500** may be utilized to evaluate timing measures of the bus trace between the host computer **140** and the following devices: any type of storage device, such as, without limitation, removable media disc drives, tape drives, quarter-inch cartridge tapes, digital audio tapes, 8mm tapes, digital linear tapes, optical disc drives, magneto-optical drives, write once read many drives, CD-ROM drives, CD-ROM recorders and DVD-ROM recorders, DVD-RAM, CompactFlash, scanners, bar code readers, printers and any other peripherals that may be connected to a host computers between which data and control communications may occur. Moreover, the host computer **140** may be replaced by any of the aforementioned devices such that neither device connected to the bus **160** is a host computer **140** or a disc drive **100**. Furthermore, the information included on the report generated by the display operation **622** may be uploaded to a result database, wherein statistics of the timing measures and comparisons of the timing measures to the protocols maybe maintained on a product and firmware basis. With particular reference to the define operation **602**, the evaluation process may be scripted and even further automated in some fashion such that no user intervention is required. Moreover, a further level of artificial intelligence may be incorporated into the evaluation process to identify and measure anomalous timing measures that, although not defined by the applied industry standard, may be so substantially different from other timing measures that the measures indeed warrant evaluation. Likewise, a timing measure may be defined only using a single timing measure condition, and not a pair of conditions, as described herein. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.